NAL PROPOSAL No. 0160

Scientific Spokesman:
Uriel Nauenberg
Duane Physical Laboratories
University of Colorado
Boulder, Colorado 80302

FTS/Off-net: 303 - 447-1000
443-2211
Ext. 8713 or 6514

PROPOSAL TO SEARCH FOR THE DECAY MODE

$K_S \rightarrow \mu^+ \mu^-$

Robert Messner, Robert Morse, Marshall Mugge
Uriel Nauenberg, Allan Franklin, & Tai Ho Tan

September 1971

PROPOSAL TO SEARCH FOR THE DECAY MODE

$K_S \to \mu^+ \mu^-$.

Robert Messner, Robert Morse, Marshall Mugge
Uriel Nauenberg, Allan Franklin, & Tai Ho Tan

Correspondent: Uriel Nauenberg
Duane Physical Laboratories
University of Colorado
Tel. (303) 443-2211
Ext. 8713 or 6514

A B S T R A C T

We propose to search for and observe the decay mode $K_S \to \mu^+ \mu^-$ if the branching ratio for this mode is $\geq 10^{-10}$. Later on we would like to search for the decay modes $K_L \to \mu^+ \mu^-$ and if necessary $K_S \to \mu^+ \mu^-$ to levels of 10^{-11}.

Recently experimenters [1] who tried to measure the decay rate $K_L \to \mu^+ \mu^-$ have reported the startling result that they have not been able to detect this decay mode indicating that its decay rate is below that calculated to be its lower limit namely [2]

$$\frac{K_L \to \mu^+ \mu^-}{K_L \to \text{all}} \gtrsim 6.8 \times 10^{-9}$$

The experimental upper limit is 1.8×10^{-9}. Recently it has been speculated that this may be due to accidental cancellations due to the C P violating character of $K_S - K_L$ system.[3] In such a case one can predict that the $K_S \to \mu^+ \mu^-$ decay rate could be quite large, namely

$$\frac{K_S \to \mu^+ \mu^-}{K_S \to \text{all}} \gtrsim 5 \times 10^{-7}$$

If on the other hand one assumes that $R(K_S \to \gamma\gamma) = R(K_L \to \gamma\gamma)$ [4] or

$$\frac{K_S \to \gamma\gamma}{K_S \to \text{all}} = .8 \times 10^{-6}$$

then in the absence of CP violation one expects

$$R(K_S \to \mu^+ \mu^-) \approx R(K_L \to \mu^+ \mu^-)$$

or
$$\frac{K_S \to \mu^+ \mu^-}{K_S \to \text{all}} \gtrsim 6.8 \times 10^{-9} \times \frac{T(K_S)}{T(K_L)}$$

$$\gtrsim 1.1 \times 10^{-11}$$

At present the best experimental limits on $K_S \rightarrow \gamma\gamma$ is [5]

$$\frac{K_S \rightarrow \gamma\gamma}{K_S \rightarrow \text{all}} < 2 \times 10^{-3}$$

and on $K_S \rightarrow \mu^+ \mu^-$ is [6]

$$\frac{K_S \rightarrow \mu^+ \mu^-}{K_S \rightarrow \text{all}} \leq 7.3 \times 10^{-6} .$$

We propose to search for the decay mode $K_S \rightarrow \mu^+ \mu^-$ and hopefully to detect it if its branching ratio is

$$\frac{K_S \rightarrow \mu^+ \mu^-}{K_S \rightarrow \text{all}} > 10^{-10}$$

Later on, if possible, (if our equipment works as expected and can be extrapolated to larger sizes) we propose to carry on the search for both the decays $K_S \rightarrow \mu^+ \mu^-$ and $K_L \rightarrow \mu^+ \mu^-$ to levels of 10^{-11}.

EXPERIMENTAL DESCRIPTION

There are two properties of the NAL machine that make it most useful in the search for this decay.

(a) Large numbers of K_S at a reasonable distance from the target which we have chosen to be 10 meters.

(b) Low $\pi \to \mu$ decay probability ($\sim 4\times10^{-3}$) which is the source of background.

We propose to use the neutral hyperon beam designed for the survey proposed by R. H. March, L. G. Pondrom and O. E. Overseth (NAL proposal #8). The beam's intensity and momentum spectrum are based on the yields calculated by T. G. Walker [7].

The apparatus to be used in this experiment is shown in figure #1. We have already run Monte Carlo generated events of the type $K_S \to 2\pi \to 2\mu$ to determine the background level. Some of the parameters of the design are shown in Table #1.

TABLE #1

Distance of apparatus from the Target	10 meters
Solid Angle	4×10^{-7}
Decay region	5 meter
Number of K_S decays/10^{10} protons	10^5
Trigger rate due to $K_S \to 2\pi \to 2\mu$	.3 /pulse of 10^{10} protons
Trigger rate due to $K_L \to \pi \mu \nu \to \mu \mu \nu$	$\sim$ 1/pulse of 10^{10} protons
Detection efficiency for $K_S \to \mu^+ \mu^-$	.75
Front Chamber Spatial Resolution	125 microns
Back Chamber Spatial Resolution	200 microns
Multiple Scattering/Chamber Module	10^{-3}/p (Bev)
Magnet (BL = 1370 Kg-in)	Argonne Labs BM-109 (24" x 8" x 72")

With these parameters the background (after kinematic constraints) due to the process $K_S \to \pi^+ \pi^- \to \mu^+ \mu^- \sim 1/10^{10}$ K_S decays. The background from $K_L \to \pi \mu \nu \to \mu \mu \nu$ should be smaller. We are presently checking this with a computer program. An essential requirement to keep the background low is an accurate localization of the source of Ko's. ($\sim <$ 5mm proton beam diameter). Figures 2 and 3 show the resolution of the apparatus.* (see below)

Each of our front chambers (for example an X module in figure #1) consists of 4 Charpak Chambers (15 x 15 cms.^{2}) with 20 μ wire diameter and a 1 mm wire separation[8]. Each of the chambers have the wires in each module offset relative to the other so that the effective wire separation is 0.25 mm. The back chambers are 40 x 40 cms.^{2} with wire spacing 1.5 mm. Each one of these Chamber modules presents 5 x 10^{-5} interaction lengths. With 10^8 neutrons in the beam this presents a counting rate of 5 x 10^3/sec. which is manageable with Charpak Chambers. The back chambers do not need to be sensitive in the beam region because the decay products are swept apart by the magnet. Because of the large neutron flux our beam line will be in vacuum to minimize the number of interactions. One event will consist of at least 2 track triggers in the Chambers and coincidence in the scintillation-absorber hodoscope to detect muons. The 10 meters of iron are not definite since we first would like to study the strong interaction shower penetration due to 50 Gev/c pions. Only $\approx$ 20% of the muons from K_S decays will not penetrate 10 meters of iron.

Equipment Requirements. We will supply the Chambers, Readout and On Line Computer. We request NAL to supply the 10 meters of magnetized absorber after the target, the momentum analyzing magnet and the 10 meter muon detection absorber.

Running Time. At 1000 pulses/hour and 10^{10} protons on target we are requesting 400 hours of running time to reach the level of 10^{-10}. In addition, we are requesting 300 hours of debugging time. This can be done with a minimum of beam on the target.

---

*The combined mass of the 2 μ's has a half width at half max. of 4.5 Mev. In addition we have additional rejection of $K_S \to 2\pi \to 2\mu$ type events (not included in the $1/10^{10}$ estimate) from spatial requirements that the decay track have a straight line trajectory between chambers. A rough estimate indicates a factor of $\approx$ 10 additional rejection.

Personnel. The graduate students and research associate will turn their attention fully to this experiment when approved. The faculty members are 50% time since they teach. In addition, in the near future we hope to have additional members. At present we are running an experiment at SLAC and we hope to finish in March of '72. We propose to be ready to run at NAL 1.5 to 2 years after approval.

REFERENCES

1) A. R. Clark, T. Elioff, R. C. Field, H. J. Frisch, R. P. Johnson, L. T. Kerth, and W. A. Wenzel (Phys. Rev. Letters 26, 1667; 1971).

2) M. A. Bagi Beg, Phys. Rev. (32, 426 (1963); L. M. Sehgal Nuovo Cimento 45,785 (1966), C. Quigg and J. D. Jackson UCRL Report #18487.

3) N. Christ and T. D. Lee (to be published in Physical Review).

4) This rate has been measured.

$$\frac{\Gamma(K_L \to \gamma\gamma)}{\Gamma(K_L \to \text{all})} = (5.2 \pm 0.5) \times 10^{-4}$$

M. Banner, J. W. Cronin, J. K. Liu, and J. E. Pilcher; Phys. Rev. Letters, 21, 1103 (1968).

5) Work being done by us at University of Colorado (Unpublished) and D. Cline, et. al. (Preprint).

6) B. D. Hyams, N. Koch, D. C. Potter, L. Von Lindern, E. Lorenz, G. Lutgens, U. Stierlin, and P. Weilhammer, Phys. Letters 29B, 521 (1969).

7) T. G. Walker 1968 NAL Summer Study B-5-68-24 Vol. II, P. 59.

8) M. Atac and J. Lach Nuclear Instruments, and Methods, Vol. 86 (1970), P. 173.

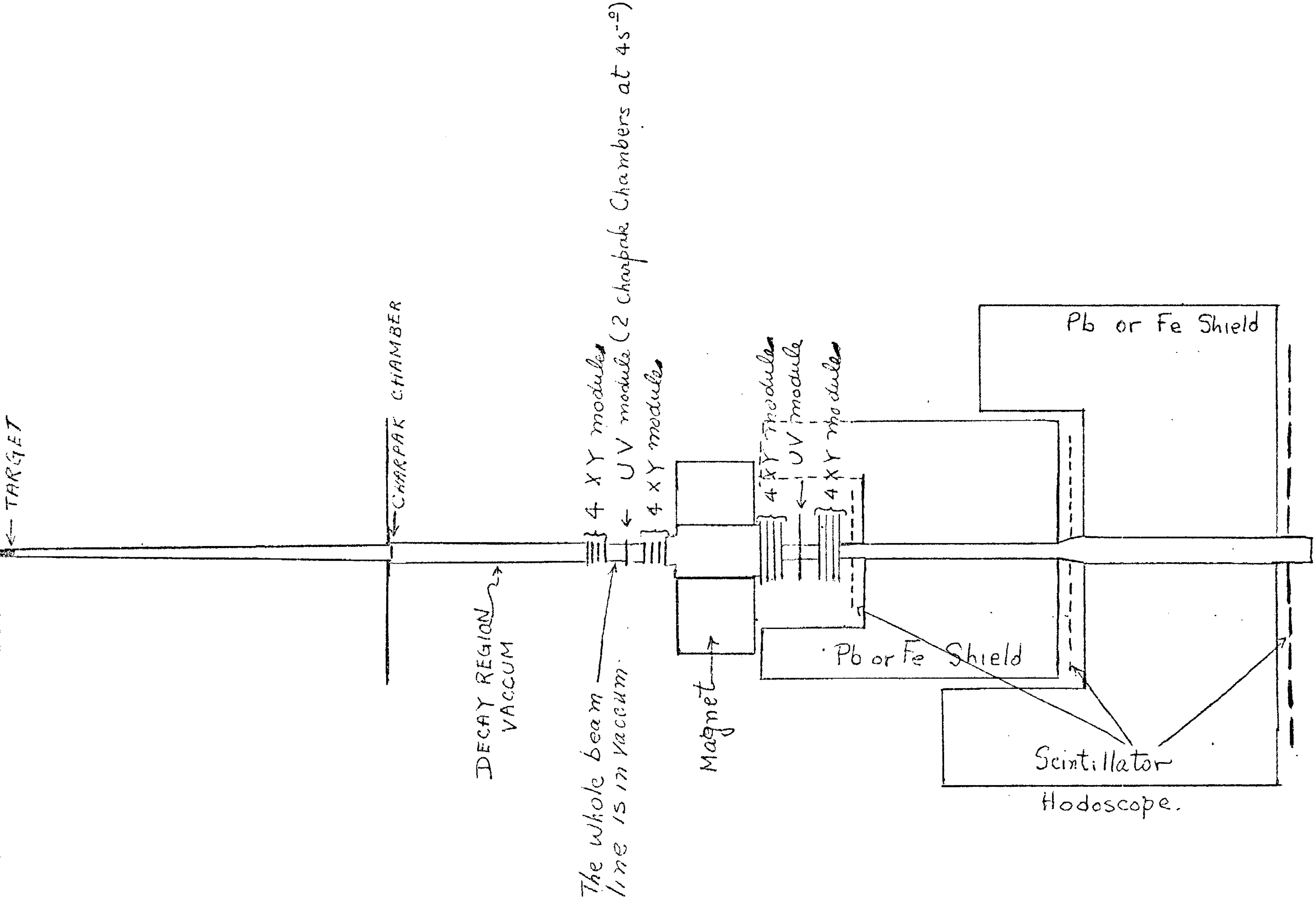

FIG 1

Longitudinal Scale $\frac{1}{3}''$ = 1 mete
Transverse Not to scale.

P of the μ in K_o Center of Mass

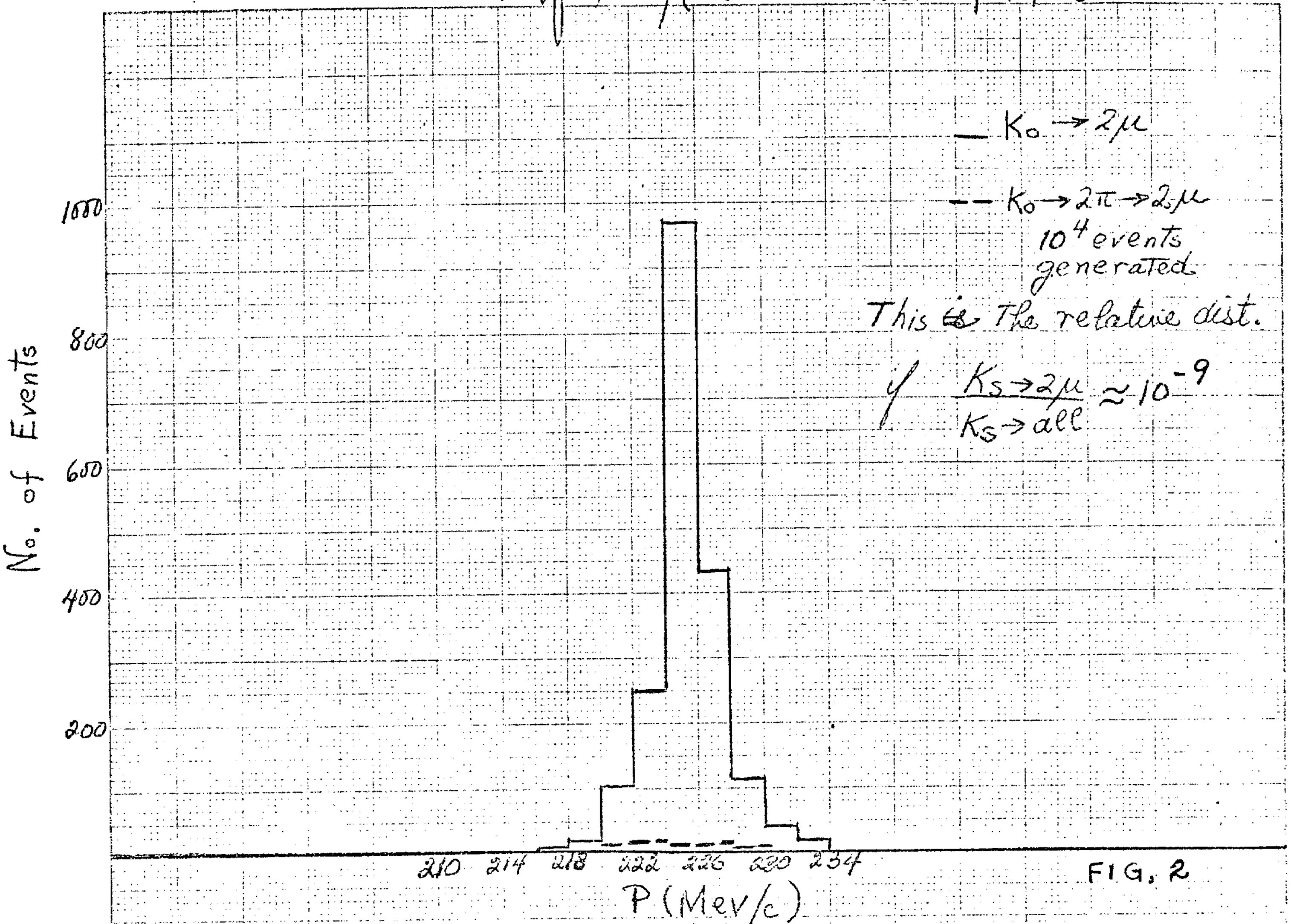

FIG. 2

K_o Production Point

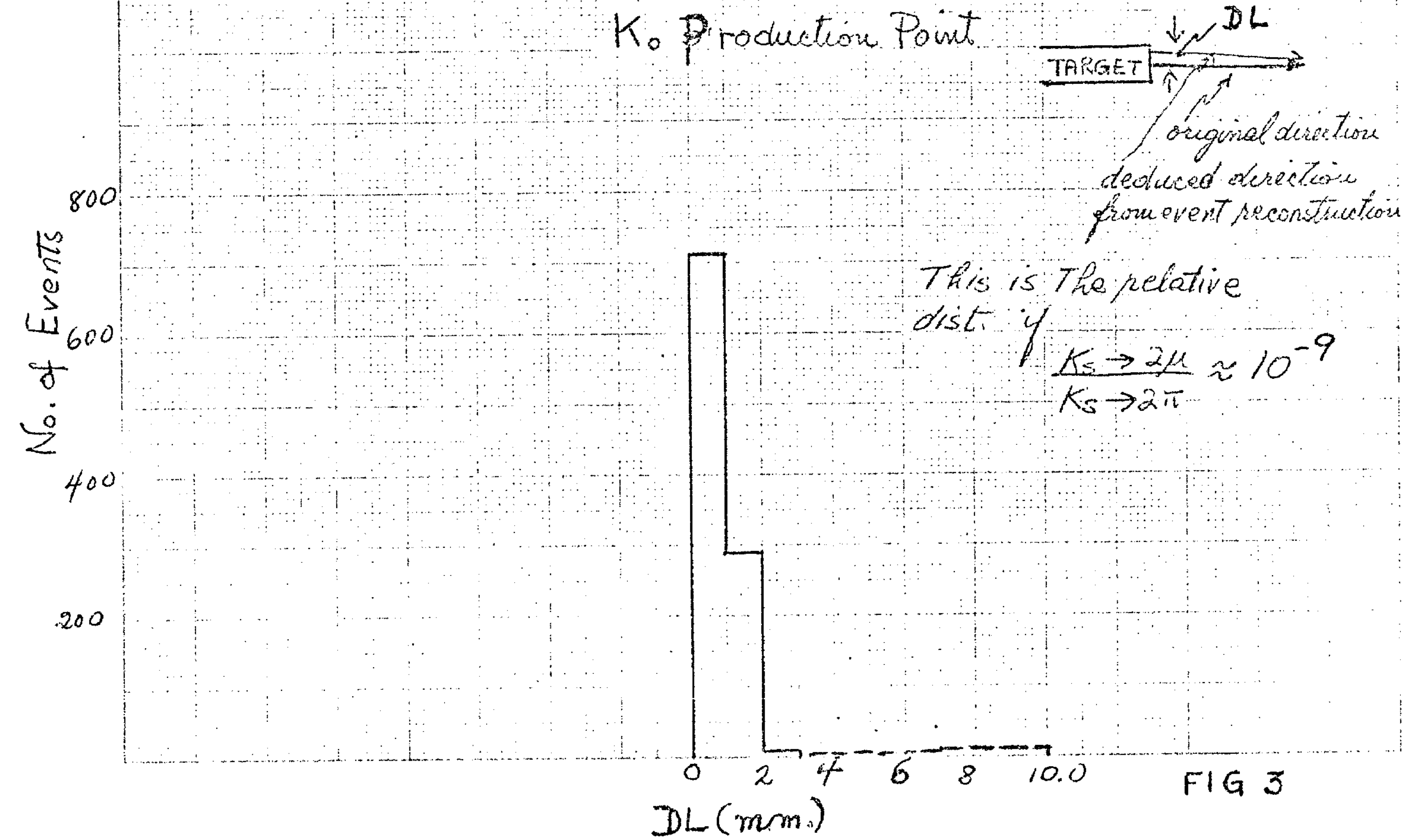

FIG 3

IMPROVEMENTS AND ADDENDUM TO NAL PROPOSAL #160

Detection of the $K_s \to 2\mu$ Decay

We have now a complete computer program that reproduces the equipment with its expected resolution and follows exactly our kinematic analysis plan. We would like to make the following comments:

1) The expected number of triggers from $K_s \to 2\pi \to 2\mu$ decays is $3.4 \times 2/3 = 2$ triggers per 10^5 K_s decays in good agreement with our previous number.

2) If we demand that the $K_s \to 2\mu$ signal have a combined mass and center of mass momenta in the range

$$M_{12} > 480 \text{ Mev}/c^2$$

$$P_1(\text{c.m.}) > 222 \text{ Mev}/c$$

$$P_2(\text{c.m.}) > 222 \text{ Mev}/c$$

and that the K^o point within 6 mm of the target center we find no events at an effective branching ratio level of $K_s \to 2\mu/K_s \to \text{all} \approx 4 \times 10^{-10}$. Hence this is an improvement over the previous requirement that the source of Ko's had to be known very well.

Figures 1 and 2 show the distribution of the combined mass of the $2\pi \to 2\mu$ tracks after reconstruction and Pcm of one track if the other is required to be > 220 Mev/c.

The Random Event Generator program generates each one of the tracks from $K_s \to 2\pi$ decay, records the position at each chamber and allows multiple scattering at each chamber. The pions are then allowed to decay, into muons and the muon track is recorded as it moves through the subsequent chambers. Each chamber x and y is then moved around within the chamber resolution and the track is then reconstructed from the coordinate positions and the known magnetic field of the spectrometer magnet. The chambers size are 15×15 cms^2 in the front with a 150 micron spatial resolution and the back chambers are 40×40 cms^2 and a spatial resolution of 300 microns. The K_s momentum is the vector sum of the 2 track momenta and this is used to determine Pc.m. and the K_s origin by extrapolating the K_s direction to the target position.

3) The detection of $\pi \to \mu$ decays by observing a poor χ^2 in the fit to the line reconstruction in the front and back chambers is not very helpful in reducing the background by an order of magnitude even though in about $\sim$ 20% of the π μ decays within the chambers a kink can be observed. This is in contradiction to our previously optimistic view.

4) We would like to use a combination of Charpak Chambers and High Resolution Cryogenic Wire Chambers. In this way we plan to have both time resolution with the Charpak Chambers and Spatial Resolution with the Cryogenic Chambers. We plan to use two cryogenic chambers at the beginning and end of the spectrometer arm before the bending magnet and "maybe" the same in the arm after the bending magnet.

5) We also would like to be able to put a 2.5 cm. thick Pb stopper in the beam channel to see its effect on reducing the background due to gammas in the beam. We propose to build in collaboration with NAL a remotely driven motor that would allow us to put in or out such a Pb piece. We would like to place it about 3 meters after the target.

Uriel Nauenberg

Uriel Nauenberg

Combined Mass Distribution

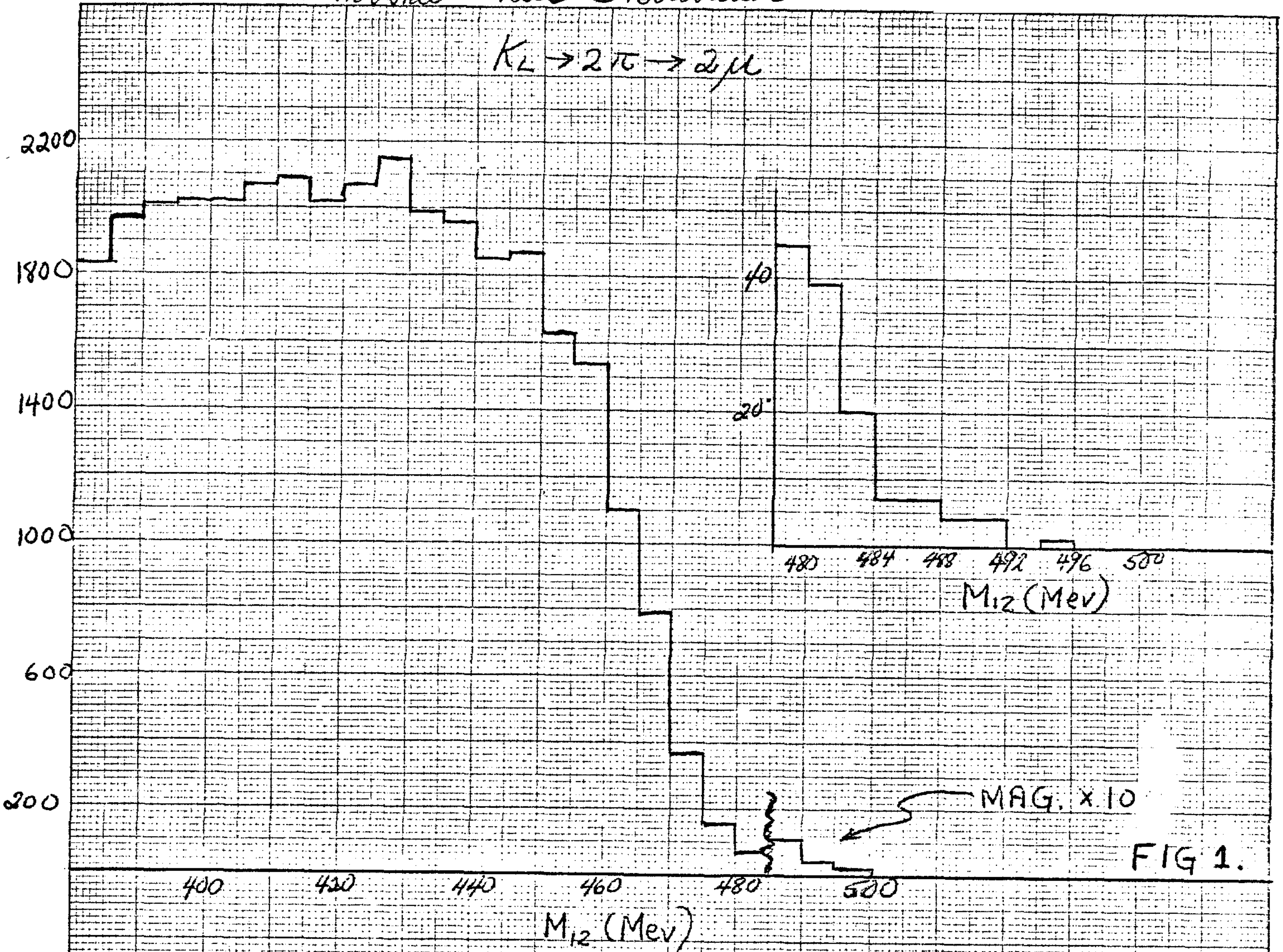

FIG 1.

C.M. Momentum Distribution if one Track has $P_{c.m.} > 220$ Mev

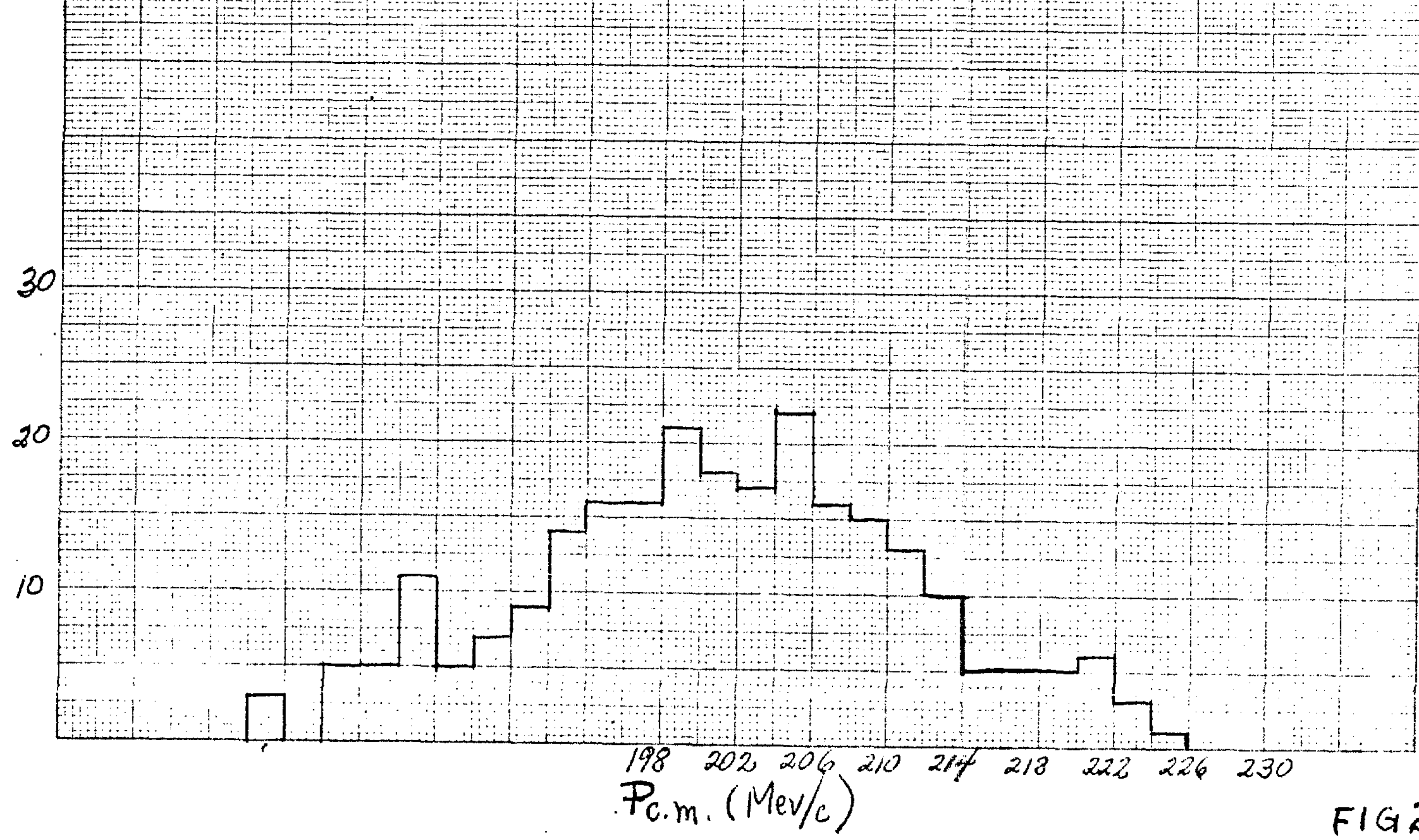

FIG 2